Appraisal of Groundwater Quality and Hydrogeochemical Process in Handri River Basin of Kurnool District, Andhra Pradesh, India

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ABSTRACT

The present study carried out to assess the water quality and hydrogeochemistry of groundwater in the Handri river basin of the Kurnool district of Andhra Pradesh. Total of 41 groundwater samples was collected and analyzed for their physicochemical parameters such as pH, electrical conductivity, total hardness, total dissolved solids, total alkalinity, and major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, F^-, NO_3^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}). The analytical results were compared with drinking water standards as prescribed by the Bureau of Indian Standards and the World Health Organization (WHO) for domestic usage and irrigation suitability. The cation dominance trend is $Na^+ > K^+ > Ca^{2+} > Mg^{2+} >$ while anion dominance trend is $Cl^- > HCO_3^- > NO_3^- > SO_4^{2-}$. The groundwater of the area is slightly alkaline. The major hydrochemical facies of groundwater were identified using Piper trilinear diagram. This plot showed that most of the samples fall in the field of Na-Cl, mixed $NaHCO_3$ type. The concentrations of chlorides, fluorides, and nitrates are above the maximum permissible limit (WHO, 1993) while sodium, potassium, and calcium, were slightly above the permissible limit. The USSL and Wilcox diagrams of the study area revealed that most of the groundwater samples fall in the field of C3-S4, unsuitable indicating high salinity, high sodium percentage, and high sodium absorption ratio. The present study concludes that the majority of the samples in the study area are not suitable for domestic and agriculture purposes thereby, recommended to follow the effective management of groundwater resources.

Key words: Hydrogeochemistry, Water quality, Handri river basin, Kurnool, Andhra Pradesh.

1. INTRODUCTION

Groundwater is of high demand because of specific properties that are not accessible in surface water. Intensive agricultural activities have increased the demand for groundwater resources in India. The quality of groundwater is key to support life [1]. Groundwater majorly controlled by natural and anthropogenic factors, such as geological structure, the composition of precipitation [2], geochemical process, the interaction between the groundwater and aquifer minerals [3], and human activities. The interaction of rock-water results in various water types [4]. The groundwater chemistry depends on different hydrogeochemical processes that the groundwater undergoes over space and time. The hydrogeochemical processes of the groundwater system help to obtain an insight into the contributions of rock and soil-water interaction and anthropogenic influences on groundwater. The geochemical processes are responsible for the spatio-temporal variations in groundwater chemistry [5,6]. Groundwater chemistry, in turn, depends on several factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water, and inputs from sources other than water-rock interaction [7-10]. The quality of groundwater is dependent on the processes, reactions that have acted on the water from the moment it condensed in the atmosphere to the time it discharged by a well. Therefore, the quality of groundwater varies from place to place, with the depth of water table, and from season to season, and it also primarily governed by the extent and composition of dissolved solids present in it. Worldwide, aquifers are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural, and land mining activities. In recent years, an increasing threat to groundwater quality due to human activities has become of great importance [11]. The geochemical study reveals the quality of groundwater that is suitable for drinking and irrigation uses; therefore, it proposed to investigate/study the hydrogeochemical characteristics and quality factors in Handri river basin of Kurnool urban watershed in Andhra Pradesh.

2. MATERIALS AND METHODS

2.1. Geology of the Study Area

The study area (i.e., Handri river basin) is located between latitudes 15°14'1"N and 15°53'40"N and longitudes 77°20'13" E and 78°9'25" E. The study site areal extent is approximately 3398.54 km^2 and is situated at about 2 km west of Kurnool city, Andhra Pradesh (Figure 1). Kurnool urban agglomeration is the fifth most crowded city in the Kurnool district of the Indian state of Andhra Pradesh. The city lies on the banks of the Tungabhadra River. The Handri and Neeva rivers also flow through the city [12]. The major part of the district in the west
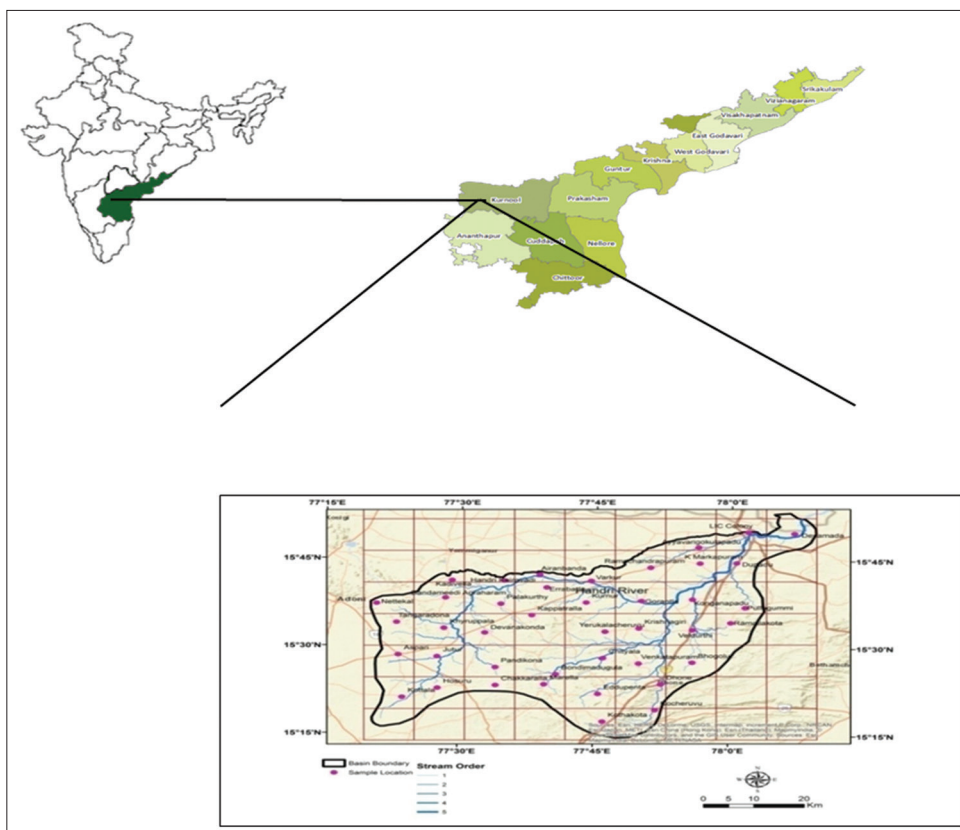
Figure 1: Geographical Location map of Handri river basin of Kurnool district with sampling locations.

is occupied by granite gneisses, while the eastern part underlain by quartzite, shales, and lime stones of Cuddapah supergroup and Kurnool group. The recent alluvium confined to the significant stream and river courses such as Krishna, Tungabhadra, Gundlakamma, and Kuderu.

2.2. Climate and Rainfall

The atmosphere in this region is tropical, with seasonal rainfall. The temperature of this region in sweltering summer is as high as 42°C, and the least temperature is 15°C. This zone is known for its wide variation in contour, substantial greenery, low rainfall, and assortment variety in meteorological parameters. The Kurnool district has an average annual rainfall of about 665mm, and it ranges from nil rainfall in January and December to 139.6 mm in September. August and September are the wettest months of the year. The mean seasonal rainfall distribution is 455.9 mm in southwest monsoon (June–September), and in northeast monsoon (October–December), this is about 133.7 mm. The percentage distribution of rainfall is about 69% in southwest monsoon and 20.1% in northeast monsoon (Central Ground Water Board, 2013) [13].

2.3. Hydrogeology

Groundwater occurs in all the geological formations in the Kurnool district. The water occurs under confined conditions in shallow weathered zones and semi-confined conditions in joints, fractures, and fissures. The occurrence of joints and fissures extends up to the depth ranging from 20 to 100 m below ground level. In Panyam quartzes under unconfined and semi-confined conditions in the weathered zone, sheared zones, joint planes, and bedding contacts (Geological Survey of India, 2001) [14].

2.4. Sample Collection and Analysis

Around the Handri river basin, 41 groundwater samples were collected in July 2017. Using a portable GPS device, sampling locations were recorded, and they are shown in Figure 1. Water samples are collected in 1 L and 100 ml polypropylene (PP) bottles after pumping the hand pumps for 10 min. Before the collection of samples, the bottle was rinsed 2 times with water and filled to avoid air bubbling. The collected water samples in the field were analyzed for electrical conductivity (EC), total dissolved solids (TDS), and major cations such as calcium, magnesium, sodium, and potassium and anions such as bicarbonate, carbonate, chloride, fluoride, and sulfate, adopting the standard methods [15]. According to the objectives of the investigation and the geology, the sampling methods were chosen. For measuring the strength of the linear relationship between these parameters, the Pearson coefficient was calculated.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Parameters

3.1.1. Hydrogen ion concentration (pH)

pH is a key parameter of groundwater in regulating the metabolic processes of the body. The normal pH range for groundwater systems is between 6 and 8.5. The pH values in the groundwater samples present study varied from 6.9 to 8.7, with an average value of 7.64. This shows that the quality of groundwater of the study area is within the desirable limit.

3.1.2. TDS

TDS represents the total concentration of dissolved substances in groundwater that decides its usage for drinking, irrigation, or industrial purposes. The concentration of dissolved substances in water is given by the weight of the material on evaporation to dryness up to temperature of 180°C. TDS values expressed in mg/L. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions. The TDS value of groundwater greater than 1000 mg/L

usually referred to as brackish water and less than 1000 mg/L referred to as freshwater. In the study area, the TDS ranges from 480 mg/L to 5479 mg/L, with an average of 1710 mg/L, indicates that most of the samples, as shown in Table 1, are above the permissible limit and not suited for drinking purposes.

3.1.3. EC
The EC of water is due to dissolved salts and other inorganic chemicals. Conductivity increases as salinity increases. EC measured *in situ* immediately in the field after sample collection without filtration using portable filed meters. In the study area, the measured EC value ranges between 750 and 8430 µS/cm (Table 2 and 3). The highest value EC was obtained at Jutur village of Aspari Mandal.

3.1.4 Total hardness (TH)
The TH of the groundwater in the study area ranges from 80 to 1830 mg/L with an average of 628 mg/L (Table 4) with maximum reported value was 1830 mg/L from Jutur village of Aspari Mandal [16]. Classified groundwater is given in Table 4, according to which 82.93% of samples belongs to very hard type, 14.63% and 2.44% of water belong to hard and moderately hard type. The acceptable limit of TH (as $CaCO_3$) is 300 mg/L (World Health Organization [WHO], 1993). The groundwater study for TH shows that the majority of the samples fall under the very hard water category (Table 4). The hardness of water is due to the presence of alkaline earths such as calcium, magnesium, and exists in bicarbonate forms.

3.2. Hydrogeochemistry

3.2.1. Piper trilinear diagram
In the field of hydrogeology and groundwater analysis, Piper trilinear diagram [17] is a potent tool for visualizing the relative abundance of common ions in water samples. Piper is useful in understanding the total

Table 1: Groundwater classification based on total dissolved solids (Davis and Dewiest 1966).

Total dissolved solids(mg/L)	Classification	Sample numbers	Number of samples	% of samples
<500	Desirables of drinking	4,7,34,38	4	9.76
500–1000	Permissible for drinking	9, 12, 13, 16, 19, 26, 27, 29, 30, 35, 36	11	26.83
1000–3000	Useful for irrigation	1, 2, 5, 6, 8, 10, 11, 14, 15, 17, 18, 20, 21, 23, 24, 25, 28, 31, 39, 40, 41	21	51.22
>3000	Unfit for drinking and irrigation	3, 22, 32, 33, 37	5	12.19
Total			41	100

Table 2: Summary statistics of the analytical data.

Water quality parameters	Units	Minimum concentration	Maximum concentration	Average	Median	Mode
pH		6.90	8.70	7.63	7.70	7.8
EC	µS/cm	750.00	8430.00	2536.00	1870.00	1760
TDS	mg/L	487.50	5479.50	1648.40	1215.50	1144
TH	mg/L	80.00	1830.00	610.98	540.00	350
DO	mg/L	0.00	0.20	0.02	0.02	0
F^-	mg/L	0.15	3.82	1.22	1.12	0.65
Cl^-	mg/L	20.92	2488.59	527.13	358.15	#N/A
NO_3^-	mg/L	1.42	1609.76	312.90	197.43	#N/A
SO_4^{2-}	mg/L	0.00	1.52	0.10	0.00	0
HCO_3-	mg/L	20.00	635.00	365.49	325.00	325
Na^+	mg/L	0.00	296.21	59.66	13.49	0
K^+	mg/L	0.00	168.34	21.56	4.78	0
Ca^{2+}	mg/L	0.00	235.91	40.49	0.00	0
Mg^{2+}	mg/L	0.00	24.64	1.05	0.00	0
RSC	meq/L	20.00	590.00	328.83	305.00	325

Table 3: Groundwater classification based on electrical conductivity.

Electrical conductivity	Classification	Sample numbers	Number of samples	Percentage of samples
<1500	Permissible	4, 7, 9, 12, 16, 19, 20, 26, 27, 29, 30, 34, 35, 36, 38	15	36.58
1500–3000	Not permissible	1, 5, 6, 10, 11, 13, 15, 17, 18, 21, 23, 24, 25, 28, 31, 40, 41	16	39.02
>3000	Hazardous	2, 3, 8, 14, 20, 22, 32, 33, 37, 39	10	24.39
Total			41	100

chemical character of water samples in terms of cation-anion pairs. A piper plot is comprised three components: A ternary diagram in the lower left representing cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), ternary diagram in the lower right representing anions (Cl^-, $HCO_3^- + CO_3^{2-}$, and SO_4^{2-}), and a diamond plot in the middle which is a matrix transformation of the two ternary diagrams. Piper trilinear diagram plotted for the chemical data of representative samples [18] from the study area. In terms of cations, most of the samples were located at the base corners of the left delta-shaped region, suggesting that most of the sampling station had sodium type water, and few are calcium type. While for the anions, most of the stations are located at the base of the right delta-shaped region of the piper diagram, suggesting that most of the stations had HCO_3^- and Cl^- type water. This plot reveals differences and similarities among groundwater samples because those samples with similar qualities will tend to plot together as groups [19]. The geochemical evolution can be understood from a Piper plot, which has been divided into six subcategories (1) $CaHCO_3$ type, (2) $NaCl$ type, (3) mixed $CaNaHCO_3$ type, (4) $CaMgCl$ type, (5) $CaCl$ type, and (6) $NaHCO3$ type. The plot shows that most of the groundwater samples fall within the field of $NaCl$ (67.8%) and $NaHCO_3$ (58.4%) type and some samples are representing, $CaCl_2$ (39.66%), $CaHCO_3$ (30.32%), and mixed $CaMgCl_2$ (41.52%) type. From the plot alkalis, (Na^+ and K^+ (76.28%) exceeds alkaline earths (Ca^{+2} and Mg^{+2}) (23.72%), Cl^- (59.33) exceeds the $HCO_3^- + CO_2^-$ (40.65%), and other anions (Figure 2).

3.2.2. Gibbs diagram

Gibbs diagrams represent the ratio of $(Na^+ + K^+)/(Na^+ + K^+ + Ca^+)$, and $(Cl^-/Cl^- + HCO3^-)$ as a function of TDS is employed to evaluate to assess the useful sources of dissolved chemical constituents such as precipitation dominance, rock dominance, and evaporation dominance.
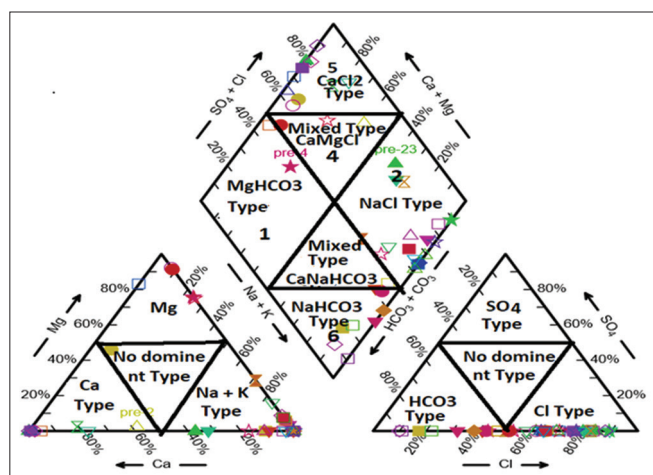

Figure 2: Piper diagram showing hydro-geochemical characteristics of groundwater.

The chemical samples of the study area plotted in Gibbs diagram are shown in Figure 3 indicating the evaporation dominance. The composition of groundwater is the significant influence of rock-water interaction and to understand the sources of dissolved chemical constituents. Therefore, groundwater chemistry helps in identifying rock water interaction by using the scattered diagram as reported by Gibbs (1970) [20].

In these diagrams, most of the samples are falling in the rock-water interaction [21] dominance area and few samples in the evaporation dominance area, which suggests that the interaction between rock chemistry and the chemistry of the water moving under the subsurface indicating the dissolution of silicate rock bearing rocks such as silicates.

3.2.3. Correlation analysis

The Na + K versus HCO_3 scatter diagram (Figure 4a) shows that most of the points show higher values of HCO_3, and very few show higher values of Na + k; this indicates that increase might be due to carbonate dissolution and ion exchange process. Na versus $Cl + SO_4$ scatter diagram (Figure 4b) shows that most of the points lie toward the right of the negative slope shows that silicate weathering is predominant for the occurrence of Na. Na versus HCO_3 scatter diagram (Figure 4c) shows that most of the points lie toward the right of the slope indicates that halite dissolution and silicate weathering takes place. Na + K versus $Cl + SO_4$ scatter diagram (Figure 4d) shows that most of the points lie below the line with higher values on the X-axis, and others with zero values on the Y-axis indicate that the silicate weathering is the main factor responsible. Cl versus HCO_3 scatter diagram (Figure 4e) shows that few of the points are located near to Equiline, which indicates that halite dissolution and 40% of the samples are above the Equiline shows that more silicate weathering is prominent.

$SO_4 + Cl$ versus HCO_3 scatter diagram (Figure 4f) shows that most of the points lie nearer to the line, and few points lie above the line indicates the process involved is silica weathering and halite dissolution. The total cations versus Na + K scatter diagram (Figure 4g) shows that most of the points lie near the equiline 1:1, which indicates that silicate weathering and cation exchange to Ca/Na is the other process taking place. Total cations versus Ca + Mg scatter diagram (Figure 4h) shows that most of the points lie nearer to the X-axis or on the X-axis, and very few points lie above the line indicates that carbonate weathering is very less and its percentage in total cations is very negligible.

3.3. Drinking Water Quality Assessment

The standard guideline values are recommended by the WHO for drinking and public health purposes are compared with parameters of the water samples (Table 5). The analytical results of physical and chemical parameters of the groundwater of the present study are shown in Table 1.

The pH of the groundwater samples varied from 6.90 to 8.70, with mean pH value of 7.64 in the study area, indicating a slightly alkaline nature

Table 4: Groundwater classification based on hardness (Sawyer and McMcartly 1967).

Total hardness as $CaCO_3$ (mg/L)	Type of water	Sample numbers	Number of samples	Percentage of samples
<75	Soft	Nil	Nil	0
75–150	Moderately high	19	1	2.44
150–300	Hard	1, 15, 16, 18, 30, 38	6	14.63
>300	Very hard	2, 3, 5, 6, 7,8, 9, 10, 11, 12, 13, 14, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41	34	82.93
Total			41	100

Table 5: Drinking water quality standards.

Water quality parameters	WHO (1993)		Number of samples exceeding allowable limits	% of samples exceeding allowable limits	Undesirable effects
WHO recommendation of groundwater for drinking purposes					
	Most desirable limits	Maximum allowable limits			
pH	6.5–8.5	9.2	Nil	Nil	Taste
EC (µS/cm)	750	1500	27	65.85	
TDS (mg/l)	500	1500	17	41.46	Gastro intestinal irritation
TH (mg/l)	100	500	22	53.65	Scale formation
Ca^{2+} (mg/l)	75	200	4	9.76	Scale formation
Mg^{2+} (mg/l)	50	150	Nil	Nil	
K^+ (mg/l)	-	12	12	29.26	Bitter taste
Na^+ (mg/l)	-	200	3	7.32	
Cl^- (mg/l)	200	600	13	31.71	Salty taste
NO_3^- (mg/l)	45	-	35	85.36	Blue baby
SO_4^{2-} (mg/l)	200	400	Nil	Nil	Laxative effective
F^- (mg/l)	-	1.5	11	26.82	Fluorosis
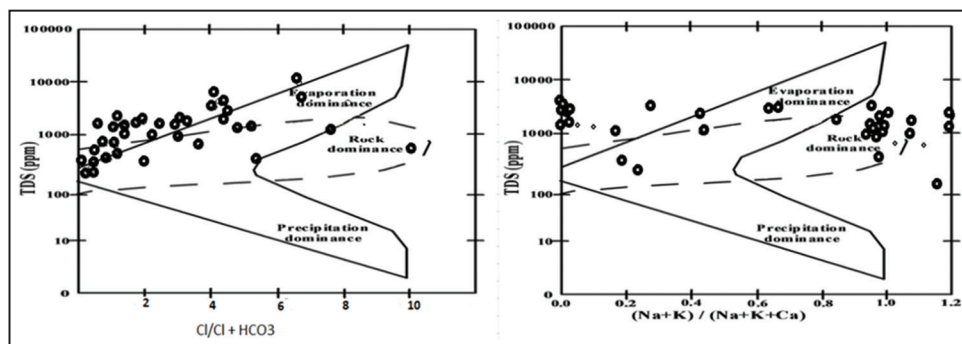
Figure 3: Gibbs diagram for controlling groundwater quality.

of groundwater (Tables 1 and 5). pH values of all the collected samples are well inside the permissible limit as prescribed by the WHO (1993). Although pH has no direct effect on human health, most of the biochemical reactions are sensitive to changes in pH [22]. Electric conductivity (EC) values for the study area range from 487 to 5479 µS/cm at 25°C with an average value of 1710.50 µS/cm (Tables 1 and 5). The higher values of EC are due to high salinity and high mineral content at the sampling site [23]. EC value depends on TDS and increases with the concentration of TDS. TDS include all the dissolved inorganic salts in groundwater. In the study area, the TDS of groundwater range from 487.50 to 5479.5 mg/L with an average value of 1710.50 mg/L. The results suggested that 41% of the samples are exceeding the permissible limits of TDS, while 41.5% of the samples showed that EC values higher than the prescribed drinking water standards.

3.3.1. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-})
Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) in the groundwater are varying from 0 to 70 mg/L and 20 to 635mg/L with an average of 6.27 and 363.72mg/L, respectively. HCO_3^- does not show any adverse effects on human health. The results show that 61% of the samples are above the limit of 300 mg/L (WHO 1993; Tables 1 and 5).

3.3.2. Chloride (Cl^-) and sulfate (SO_4^{2-})
The chloride concentration in the groundwater samples varies from 21 to 2488 mg/L, with an average value of 527.13 mg/L (Tables 1 and 5). The desirable limit of chloride in potable water is 200 mg/L, and the

maximum allowable limit is 600 mg/L (WHO, 1993), while 36.58% of the groundwater samples exceed the permissible limit of chloride. The chloride is higher (2488.59 mg/L in Jutur village) due to the leaching of the upper soil layers by industrial and domestic activities and dry climates. Moreover, a higher concentration of Cl^- in drinking water causes a salty taste and has a laxative effect on people not habituated to it. The sulfate concentration of the groundwater samples of the study area ranges from 0 to 1.52 mg/L, with an average value of 0.13 mg/L, which is below the permissible limit of 400 mg/L (WHO, 1993).

3.3.3. Nitrate (NO_3^-) and fluoride (F^-)
Nitrate contamination in groundwater is one of the major issues in water quality studies [24]. Nitrate concentration in the groundwater of the study area varies from 1.42 to 1609.76 mg/L with a mean of 312.9 mg/L (Tables 1 and 5). The highest nitrate level is recorded at Jutur village (1609.76 mg/L), 85.36% of the samples are exceeding the maximum allowable limits. Hence, the groundwater samples not suitable for drinking purpose. The presence of a high concentration of nitrate in drinking water not only causes methemoglobinemia (blue baby syndrome) in infants but has also been reported to cause cancer [25]. Fluoride content in groundwater shows a range of 0.145–3.82 mg/L and the average value is 1.25 mg/L with highest fluoride level recorded at Dupadu village (3.82 mg/L). Nearly 26.82% of groundwater samples of the study area have more than permissible limit (1.5 mg/L) of fluoride which is not fit for drinking purposes. Granitic rocks occupy the present study region, and these are well known to
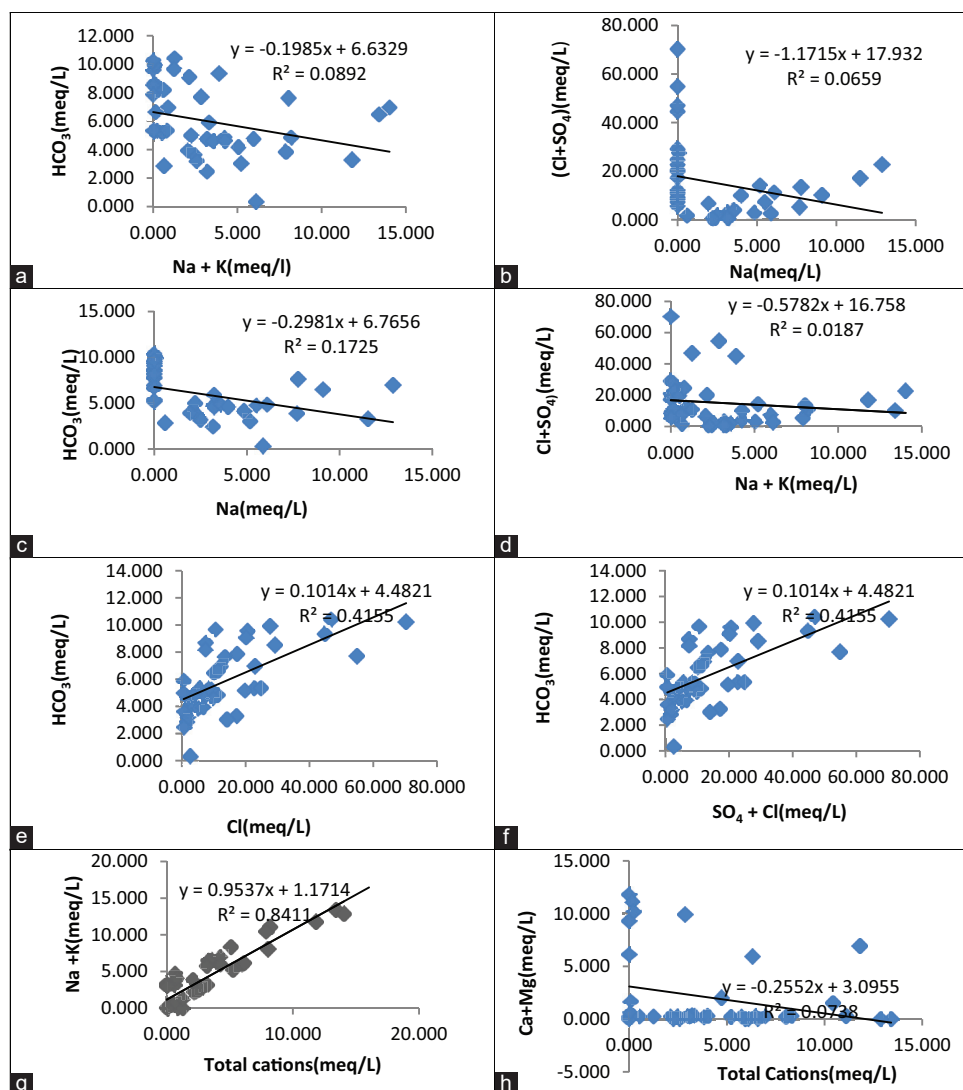
Figure 4: Scatter plots (a) Na + K and HCO$_3$, (b) Na versus Cl + SO$_4$, (c) Na versus HCO$_3$, (d) Na + k versus Cl + SO$_4$, (e) Cl versus HCO$_3$, (f) SO$_4$ + Cl versus HCO$_3$, (g) total cations versus Na + k, (h)total cations versus Ca + Mg.

contain a relatively more substantial proportion of high-fluorine minerals [26-28].

3.3.4. Na$^+$ and K$^+$

The Na$^+$ and K$^+$ values in the study area vary from 0 to 296mg/L, with an average of 63.77mg/L. According to the WHO (1993) guidelines, the maximum permissible limit is 200 mg/L, and 7.3% of the samples are above this limit. Higher concentration more than 200 mg/L, makes the water unsuitable for domestic use and causes severe health problems such as hypertension, congenital diseases, kidney disorders, and nervous disorders in the human body [29,30]. The concentration of potassium in natural water is generally <10 mg/L (WHO, 1993). The potassium concentration in groundwater in the study area varies from 0 to 168.34 mg/L, with an average value of 24.46 mg/L. The permissible limit of K$^+$ for drinking water is specified as12 mg/L as per the WHO (1993), and 29.26% of the samples are above the specified limit.

3.3.5. Calcium (Ca^{2+}) and magnesium (Mg^{2+})

Calcium concentration in the groundwater samples of the study area varies from 0 to 235.9 mg/L, with an average value of 44 mg/L (Tables 1 and 5). The solubility of calcium in groundwater alters with the amount of CO$_2$ and in the presence of HCO$_3$. The maximum allowable limit for calcium is 200 mg/L (WHO, 1993). Only 10% of groundwater samples have Ca^{2+} concentration above the permissible

limit as given by the WHO (1993) (Tables 1 and 5). Magnesium in the groundwater of the study area is varying from 0 to 24.64 mg/L, and the average value is 1.57 mg/L (Tables 1 and 5). The required, permissible limit of magnesium in groundwater for drinking purpose is 150 mg/L (WHO, 1993) and all the samples are within the permissible limits.

3.4. Irrigation Water Quality

3.4.1. Sodium absorption ratio (SAR)

Sodium hazard generally expressed as SAR. It is a measure of the amount of sodium (Na$^+$) relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the water sample [31,32]. Sodium concentration is an essential parameter in assessing the water for irrigation purposes. The water is classified concerning irrigation based on the ranges of SAR values. The physical structures of the soil get damaged due to the continuous use of water having high SAR. High sodium ions in water affect the permeability of the soil and cause infiltration problems. Sodium, when present in the soil in exchangeable form, replaces calcium and magnesium adsorbed on the soil clays and causes dispersion of soil particles.

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Where all the ionic concentration is expressed in meq/L.

Table 6: Irrigation quality of ground water based on sodium absorption ratio.

RSC (meq/l)	Classification	Sample numbers	Number of samples	Percentage of samples
<1.25	Good	1, 2, 3, 4, 13, 14, 21, 22, 32, 37	10	24.3
1.25–2.5	Doubtful	0	0	0
>2.5	Unsuitable	5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 20, 24, 25, 26, 27, 28, 29, 30, 31, 33, 34, 35, 36, 38, 39, 40	30	73.1
Total			41	100

Table 7: Irrigation quality of ground water based on residual sodium carbonate.

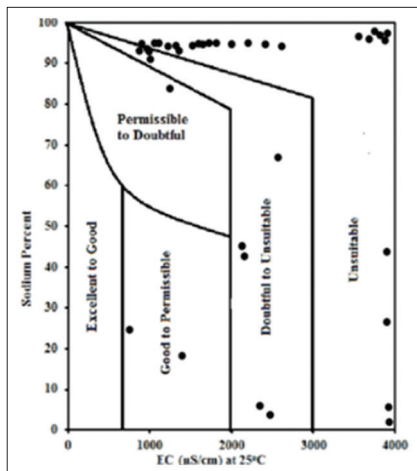| RSC (meq/l)	Classification	Sample numbers	Number of samples	Percentage of samples
<1.25	Good	3, 4, 14, 21, 22, 23, 26, 37	8	19.5
1.25–2.5	Doubtful	19	1	2.4
>2.5	Unsuitable	1, 2, 5, 7, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 20, 24, 25, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 39, 40, 41	32	78.04
Total			41	100

Figure 5: Quality of water-related to electrical conductivity and Na % (Wilcox diagram).

Figure 6: Salinity and alkalinity hazard of irrigation water in US salinity diagram.

In the study area, 73.1% of groundwater samples have high SAR (>2.5), which is unsuitable for irrigation purposes. A high SAR in irrigation water has the potential to damage soil structure and the permeability of the soil, leading to a lack of soil moisture (Table 6).

3.4.2. Residual sodium carbonate

RSC is another parameter to categorize groundwater for usage in irrigation [33]. Along with TDS, the relative abundance of sodium concerning alkaline earth and the quantity of carbonate and bicarbonate leads to the precipitation of calcium and magnesium, influencing the quality of water used for irrigation. Land irrigated by water containing high RSC becomes infertile due to the deposition of sodium carbonate, as indicated by the back color of the soil [34]. RSC is expressed in meq/L. RSC of water with higher than 2.5 is not suitable, and less than 1.25 are suitable for irrigation purposes.

RSC is calculated using the formula:

$$RSC = [HCO_3 + CO_3] - [Ca + Mg]$$

In the study area, expect few samples; all (80.44%) have values greater than 1 during the period, which indicates that water is not suitable for irrigation (Table 7).
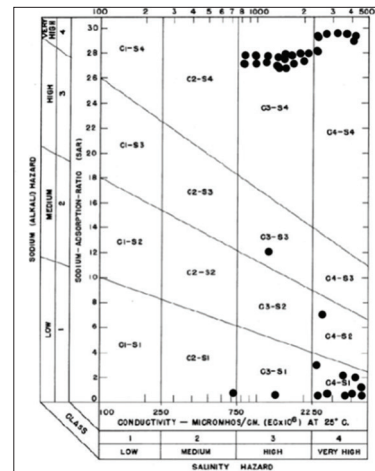
3.4.3. Sodium percentage

Sodium percentage is essential in classifying irrigation water. Sodium readily reacts with soil, which results in the clogging of particles, thereby reducing soil drainage and permeability [35,36]. Alkaline soils contain high proportions of sodium and tend to displace Ca^{2+} and Mg^{2+} ions. This exchange process gradually reduces the permeability and results in poor internal drainage. Hence, sodium concentration is vital for irrigation purposes.

The percentage of sodium is calculated using the formula as given below:

$$\%Na = \frac{(Na + K)}{(Ca + Mg + Na + K)} \times 100$$

In the present study, the % Na values range from <20% to >80%. Wilcox's (1955) diagram (Figure 5) is used for the classification of irrigated water, wherein EC is plotted against Na % (Figure 2). Based on Wilcox's classification, 63.4% of samples belong to unsuitable and remaining belongs to doubtful to unsuitable. While a high salt content in water with high EC leads to the formation of saline soils, high sodium content (SAR) leads to the development of alkaline soil.

3.4.4. Alkalinity hazard

The high concentration of dissolved ions such as sodium, bicarbonate, and carbonate in irrigation water may negatively affect the plants and soil used in agriculture, physically, and chemically. This ion decreases the soil's hydraulic conductivity which further lowers the osmotic pressure in structural cells of plants. This prevents water from entering into branches and leaves which chemically affects the plant's metabolism and development [37].

The graphical diagram of irrigated waters and the effect of EC and SAR are selected after the US Salinity Laboratory (1954) reveals that groundwater possesses high salinity with high sodium content. In the current study, all the samples come under high conductivity and high sodium content (C3-S4) as per US Salinity Laboratory (1954). The high concentrations of sodium in water cause undesirable effects on soil's property and permeability. Hence, the evaluation of sodium concentration is useful while considering the suitability for irrigation (Figure 6).

4. CONCLUSION

In the majority of the groundwater samples, analyzed parameters such as EC, TDS, Na^+, K^+, HCO_3^-, Cl^-, F^-, NO_3^-, SO_4^{2-}, and F^- exceed the desirable and maximum permissible limits of drinking water standards. The high contribution of ($Na^+ + K^+$) to total cations reveals that the chemical composition of the water controlled mainly by bicarbonate weathering and silicate weathering. The Gibbs diagram revealed that the rock dominance, which suggests that the interaction between rock chemistry and the chemistry of the water moving under the subsurface is indicating the dissolution of halite and silicate bearing rocks with groundwater. As per the USSL diagram, all water samples with different results obtained in the study indicate that most of the groundwater samples collected in the period are unsuitable for domestic and irrigation purposes. The long-term use of the water might lead to health hazards for humans and sodium hazard to soils. This leads to negative impacts on yields of crops and properties of soil. The best way is to reduce the high salinity of water for irrigation purposes, and use is by mixing high salinity and low salinity water. The groundwater in Handri river basin area is alkaline. In most of the groundwater samples, the concentration of alkalies (Na + K) exceeds over alkaline earth cations ($Ca^{2+} + Mg^{2+}$), and ($Cl^- + SO_4^{2-}$) exceeds over ($HCO_3^- + CO_3^{2-}$), and other anions. NaCl, NaHCO$_3$, and CaCl$_2$ are dominant hydrochemical facies. The groundwater chemistry of the study area is strongly influenced by the weathering of rock-forming minerals.

5. ACKNOWLEDGMENTS

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